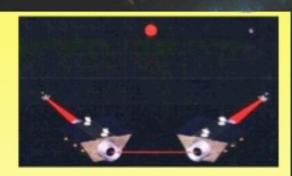
# Space-based gravitational wave observatories: Learning from the past, moving towards the future.

GW-SIG Report
Guido Mueller
University of Florida

AAS Meeting
Washington DC 2014

- M3 proposal for 4 S/C ESA/NASA collaborative mission in 1993
- LISA foreseen as ESA
   Cornerstone in 1995
- 3 S/C NASA/ESA LISA appears in 1997





#### LISA - an ESA cornerstone mission for a gravitational wave observatory

K Danzmann for the LISA Study Team (selected in Horizons 2000+ in 1997) Class. Quantum Grav. 14 1399 (1997)

Enter mission definition when funding becomes available

#### Decadal 2000 (AANM):

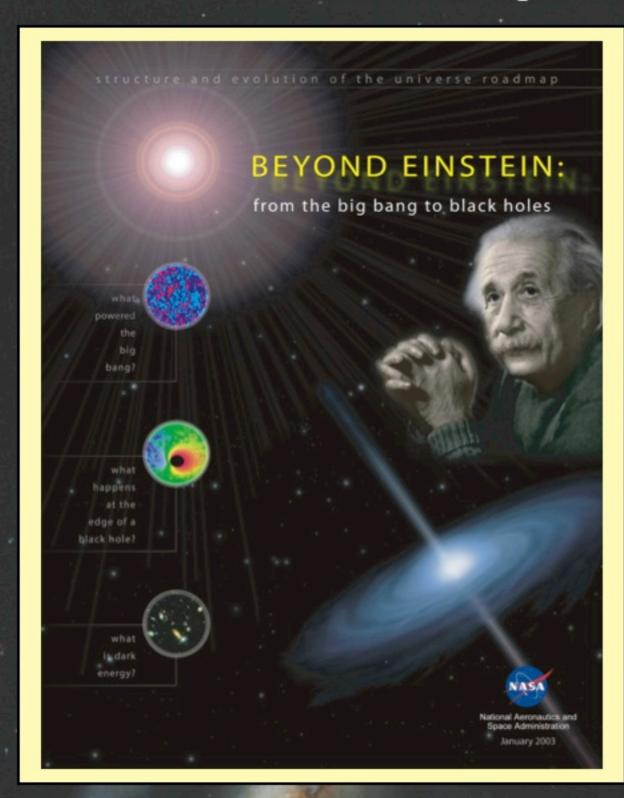
The committee's second-priority<sup>‡</sup> space-based project is the Laser Interferometer Space Antenna (LISA), which will be able to detect gravity waves from merging supermassive black holes throughout the visible universe and from close binary stars throughout our galaxy.

#### LISA INTERNATIONAL SCIENCE TEAM (LIST)

- 10 to 15 members from each side of the Atlantic
  - Chairs: Tom Prince, Karsten Danzmann
- Bi-annual meetings
  - First in June 2001/ Last in December 2010

#### LISA PROJECT OFFICES:

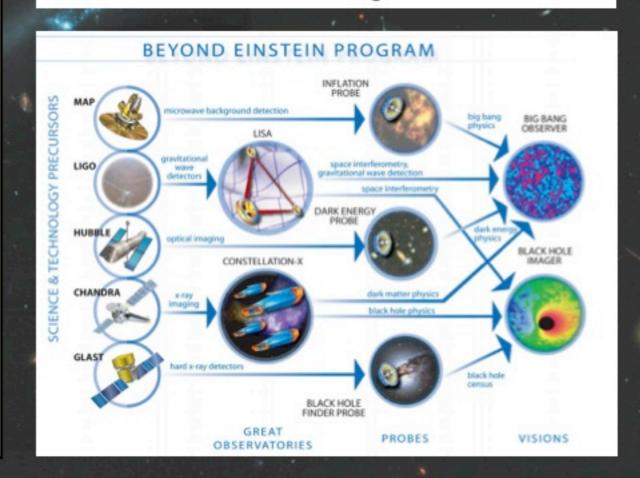
- ESA/ESTEC
  - Project Scientist: Oliver Jennrich
- NASA/GSFC
  - Robin 'Tuck' Stebbins



#### Science Objective 1. Find out what powered the Big Bang.

Research Focus Area 1. Search for gravitational waves from inflation and phase transitions in the Big Bang.

- Research Focus Area 3. Perform a census of black holes throughout the Universe.
- Research Focus Area 4. Determine how black holes are formed and how they evolve.
- Research Focus Area 5. Test Einstein's theory of gravity and map spacetime near the event horizons of black holes and throughout the Universe.



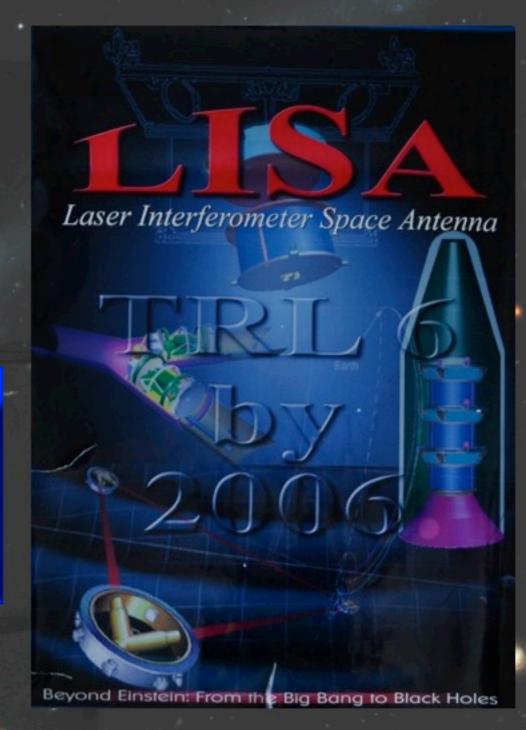
#### LASER INTERFEROMETER SPACE ANTENNA

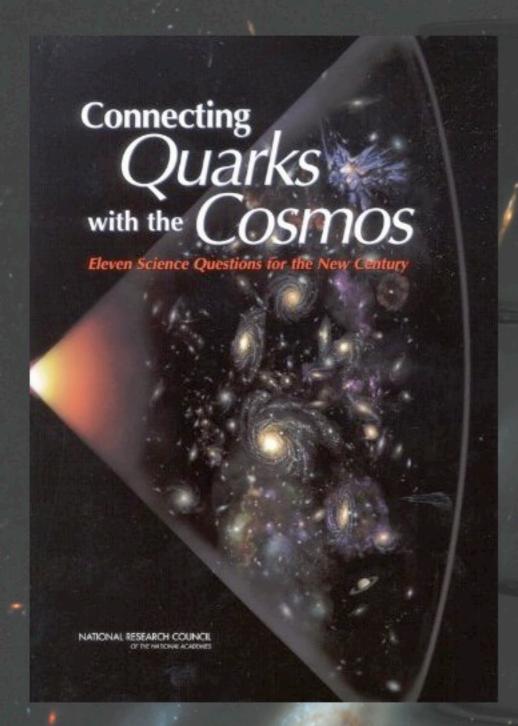
TECHNOLOGY READINESS & IMPLEMENTATION PLAN

**February 3, 2003** 

				F	ull C	ost N	IASA	Fun	ding	(ex	cludi	ing S	T-7)				
2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
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						lm	plem	entat	ion (	631	M)						
			1							C	ruise	and	Oper	ation	s (\$2	19M)	
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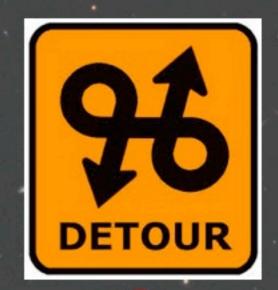
Launch in 2011!





LISA is a joint ESA-NASA project to measure low-frequency gravitational radiation from sources such as coalescing black holes and to undertake new tests of Einstein's theory. LISA will also be able to make an initial search for gravitational waves from the early universe, paving the way for future, more sensitive detectors that could possibly detect the gravitational whispers from inflation and other early universe sources.

NSF, with its experience in developing the ground-based LIGO detectors, and DOE, with its experience in optics and lasers, could play important roles in developing future gravitational-wave detectors in space.



2003 - 2008



2008 - 2010 Decadal Time

#### Decadal 2000 (AANM):

The committee's second-priority space-based project is the Laser Interferometer Space Antenna (LISA), which will be able to detect gravity waves from merging supermassive black holes throughout the visible universe and from close binary stars throughout our galaxy.

#### Have to be 1st this time?

#### Decadal 2010:

NWNH considered LISA and IXO to be compelling, highly capable, and more ambitious flagship missions than WFIRST but ranked them lower because of their required new technology development, higher cost, and technical risk, .... (Recommendation for Implementation of NWNH)

2008 - 2010 Decadal Time

#### Decadal 2010:

NWNH considered LISA and IXO to be compelling, highly capable, and more ambitious flagship missions than WFIRST but ranked them lower because of their required new technology development, higher

cost, and

Lesson learned?

Technology development and readiness is apparently really important!

Remember 2003: The three elements of

The vision missions will make direct measurement of signals from the true boundaries of our Universe.

Constellation-X and LISA can be realized within the next decade and address pressing near-term science questions.



## After 15 years of joint LISA development in March 2011...





Published online 22 March 2011 | Nature 471, 421 (2011) | doi:10.1038/471421a

News

### Europe makes do without NASA

US budget crisis forces European Space Agency to abandon plans for joint mission.

#### Stories by keywords

- · European Space Agency
- L-Class missions
- · LISA
- · IXO
- ESJM-Laplace

This article elsewhere

Blogs linking to this article

cugenie samuei Keich

The European Space Agency (ESA) is pushing ahead without NASA support for its next big science mission, as the ongoing US budget crunch and competing priorities impose serious constraints on the US space agency (see <a href="Nature 471">Nature 471</a>, 278; 2011). ESA last week told leaders of three large, or 'L-class', missions that are competing for funding to revise their proposals by leaving out the substantial US contribution that had previously been assumed.

"The decision was made very reluctantly," says David Southwood, director of science and robotic exploration at ESA. "NASA could not meet our timetable to launch."

- Telescope will track space junk
   22 April 2011
- China hopes research centre can quell food-safety fears

#### **Related stories**

- US Mars mission takes pole position 08 March 2011
- ESA on countdown to flagship mission selection

Surprised?

2011-2013

National Aeronautics and Space Administration

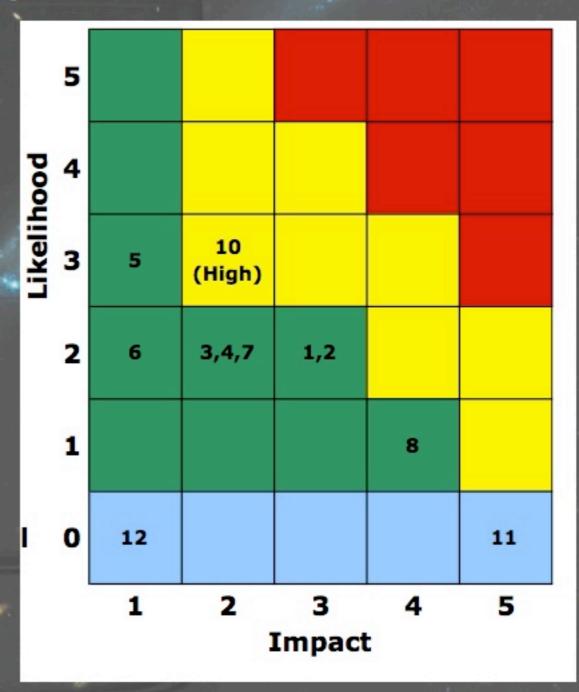


#### Gravitational-Wave Mission Concept Study Final Report

Science Performance	SGO-High	SGO-Mid	LAGRANGE/ McKenzie	OMEGA Option 1	OMEGA Option 2		
Massive Black Hole Binaries	10 M M						
Total detected	108-220	41-52	37-45	21-32	21-32		
Detected at z ≥ 10	3-57	1-4	1-5	1-6	1-6		
Both mass errors ≤ 1%	67-171	18-42	8-25	11-26	11-26		
One spin error ≤ 1%	49-130	11-27	3-11	7-18	7-18		
Both spin errors ≤ 1%	1-17	<1	0	<1	<1		
Distance error ≤ 3%	81-108	12-22	2-6	10-17	10-17		
Sky location ≤ 1 deg <sup>2</sup>	71-112	14-21	2-4	15-18	15-18		
Sky location ≤ 0.1 deg <sup>2</sup>	22-51	4-8	≤1	5-8	5-8		
Total EMRIs detected <sup>†</sup>	800	35	20	15	15		
WD binaries detected (resolved)	4 × 10 <sup>4</sup>	7 × 10 <sup>3</sup>	5 × 10 <sup>3</sup>	5 × 10 <sup>3</sup>	5 × 10 <sup>3</sup>		
WD binaries with 3-D location	8 × 10 <sup>3</sup>	8 × 10 <sup>2</sup>	5 × 10 <sup>2</sup>	1.5 × 10 <sup>2</sup>	1.5 × 10 <sup>2</sup>		
Stochastic Background Sensititvity (rel. to LISA)	1.0	0.2	0.15*	0.25	0.25		
Top Team X Risk	Moderate <sup>‡</sup>	Low	Moderate	Moderate	High		
Top Team X + Core Team Risk	Moderate <sup>‡</sup>	Low	High	High	High		
Team X Cost Estimate (FY12\$)	2.1B	1.9B	1.6B	1.4B	1.2B		

T Based on median rate; estimates for EMRI rates vary by as much as an order of magnitude in each direction.

Table 20. Summary of science return, risk, and cost for the mission concepts considered by Team X. SGO High science performance is the same as LISA. This table is repreated as Table 20 in Section 8 with additional explanation.



SGO-Mid (LISA-like): Low risk mission!



Two-arm instruments such as LAGRANGE/McKenzie lack the "GW null" channel that can be used to distinguish between stochastic backgrounds and instrumental noise, making such measurements more challenging.

<sup>‡</sup> The moderate risk for SGO High comes about from the thruster development necessary to demonstrate the required lifetime for 5 years of science operations.

## SSAC Recommendation



- EUROPEAN SPACE AGENCY
- SPACE SCIENCE ADVISORY COMMITTEE (SSAC)
- Recommendation on the selection of the L1 mission
- At its 138th meeting held the mission to be selected Programme. The SSAC cor
- The SSAC carefully considered concerning the three misses overall impact on the Science

#2 again

ESA makes decisions

AC met to recommend nic Vision NA, JUICE, and NGO. ammatic aspects entific value and the

- After an extensive discussion the SSAC came to a consensus and recommends the JUICE mission to be selected as the L1 mission leading to a launch in 2022.
- The SSAC unanimously recognized the high science value of NGO and therefore recommends continuing the necessary technology activities to enable a gravitational wave observatory to be a strong candidate for the next launch slot.
- The SSAC also recognized the science value of ATHENA and therefore recommends continuing the technology activities for enabling an X-ray observatory to be a strong candidate for the next launch slot

13

## New ESA Call for Large Missions





be addressed by the next two Large (L-class) missions in the

of the current Call, soliciting White Papers to propose science

themes and associated questions that the L2 and L3 missions should address. The submission deadline for White Papers is 24

May 2013, 12:00 CEST (noon).

Cosmic Vision 2015-2025 plan, "L2" and "L3", currently planned

with a consultation of the broad scientific community, in the form

for a launch in 2028 and 2034, respectively. This process starts

Our time now! No doubt ...

CHEOPS **EChO** 

News

**Brochure** 

▶ The Universe

**Cosmic Vision** 

## THE GRAVITATIONAL UNIVERSE

A science theme addressed by the eLISA mission observing the entire Universe



Among the, roughly, 1000 scientific supporters of the Gravitational Universe science theme, are

GERARDUS 'T HOOFT Utrecht University (Netherlands), BARRY BARISH Caltech (United States), CLAUDE COHEN-TANNOUDJI College de France (France), NEIL GEHRELS NASA Goddard Space Flight Center (United States), GABRIELA GONZALEZ LIGO Scientific Collaboration Spokesperson, LSU (United States), DOUGLAS GOUGH Institute of Astronomy, University of Cambridge (United Kingdom), STEPHEN HAWKING University of Cambridge, DAMTP (United Kingdom), STEVEN
KAHN Stanford University/SLAC National Accelerator Laboratory (United States), MARK KASEVICH Stanford University, Physics Dept. (United States), MICHAEL KRAMER Max-Planck-Institut fuer Radioastronomie (Germany), ABRAHAM
LOEB Harvard University (United States), PIERO MADAU University of California, Santa Cruz (United States), LUCIANO
MAIANI Università di Roma La Sapienza (Italy), JOHN MATHER NASA Goddard Space Flight Center (United States), VID MERRITT Rochester Institute of Technology (United States), VIATCHESLAV MUKHANOV LMU München (Germany),
GIORGIO PARISI Universita di Roma la Sapienza (Italy), STUART SHAPIRO University of Illinois at Urbana-Champaign
(United States), GEORGE SMOOT Universite Paris Diderot (France), SAUL TEUKOLSKY Cornell University (United States),
KIP THORNE California Institute of Technology (United States), GABRIELE VENEZIANO Collège de (France) (France),
JEAN-YVES VINET Virgo Collaboration Spokesperson, OCA Nice (France), RAINER WEISS MIT (United States), CLIFFORD
WILL University of Florida (United States), EDWARD WITTEN Institute for Advanced Study, Princeton (United States),
ARNOLD WOLFENDALE Durham University (United Kingdom), and SHING-TUNG YAU Harvard University (United States).

- Launch of L2 in 2028 Athena
- Launch of L3 in 2034 LISA



#2 again (or is this #3 or #7?)

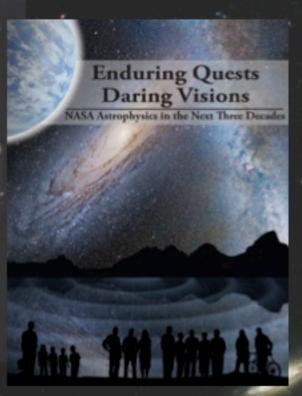
## What have we learned?

Being #2 is not good enough!



... are very good to pick your favorite citation.





#### What have we learned?

## LISA Pathfinder





are very good to pick our favorite citation.





At the end of the day ...:

• LPF hasn't flown yet!

And that is our problem.

#### What have we learned?

#### Technical readiness is:

- the key for selection
- subject to interpretation
- for LISA:
  - the Pathfinder will be a major step forward

## Will the Pathfinder be enough?

- Not to start the mission!
  - We need: Lasers, telescopes, phase meter, optical bench, lock acquisitions, point ahead and breezing angles, ...
  - Most of this is > TRL4 and (also according to TeamX): Low risk
    - We still need them ...

## Why am I hopeful?

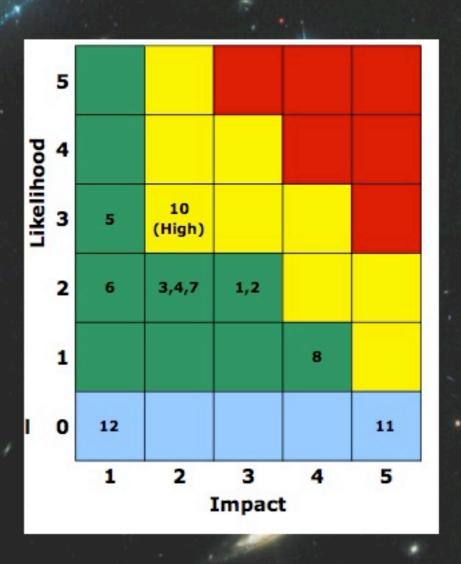




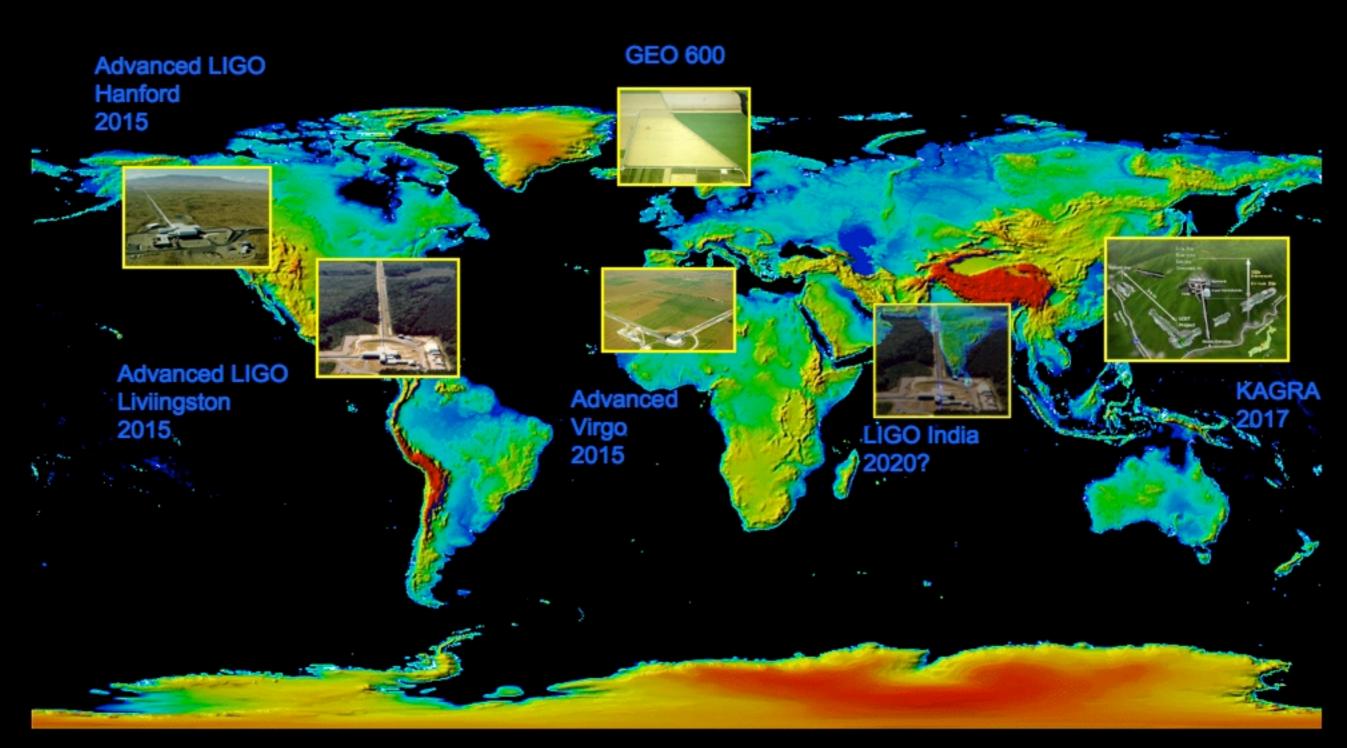
- + the independent risk assessment of TEAM X: Low Risk
- + Great Science ...

#### LISA Pathfinder

- is the technology demonstrator for our field!
- will launch in 2015!



## The Advanced GW Detector Network



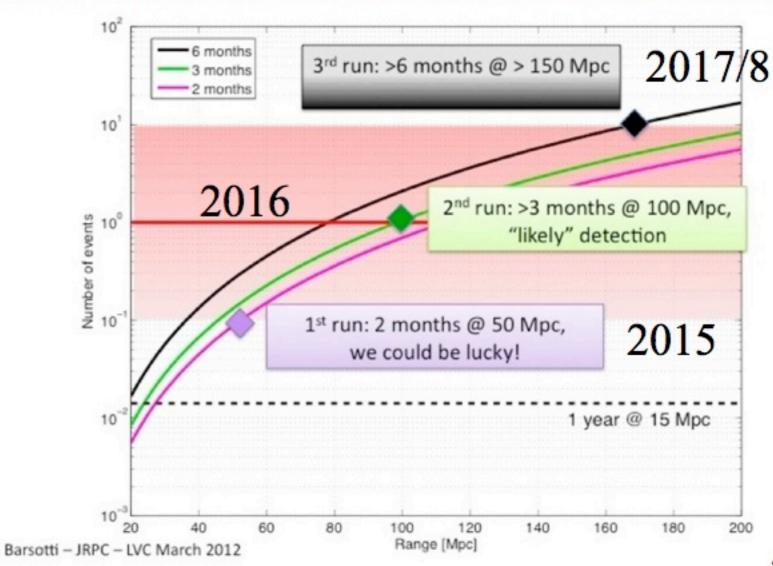




## Advanced LIGO

- - Installation 99% complete
  - All systems have seen light at least once
  - No major issues or show stoppers in sight

#### Advanced LIGO: Detection betw. 2016-2018



#### Pathfinder:

- Launch in 2015
- Results in 2016

#### Advanced LIGO:

- Science runs start in 2015
- First detection 2016-2018

#### Technical readiness

Scientific pressure

Slides from Karsten Danzmann (eLISA spokesperson) Dec. 16, 2013

## L3: Roadmap for LISA

- Launch LISA Pathfinder in 2015
- Coordination of international partners
  - Technology development until 2019
- Mission concept selection 2020
  - Payload EQM 2020 2024
  - Start industrial implementation 2025
- Launch 2034

#### Remember?

					F	ull C	ost I	VASA	\ Fur	nding	(ex	cludi	ing S	T-7)				
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Pre	-Fori	mulat	ion (	\$14M	)													
				Form	ulatio	on (\$.	209N	1)				Cos	ts ar	e in r	eal-y	ear \$	's	
							lm	plem	enta	tion (	631	M)						
							T T				C	ruise	and	Oper	ation	s (\$2	19M)	
											Φ.							_

Slides from Karsten Danzmann (eLISA spokesperson) Dec. 16, 2013

## L3: Roadmap for LISA

- Launch LISA Pathfinder in 2015
- Coordination of international partners
  - Technology development until 2019
- Mission concept selection 2020
  - Payload EQM 2020 2024
  - Start industrial implementation 2025
- Launch 2034

## International scenarios for space-based detectors

- USA
  - Scenario 1: Junior partner in eLISA
  - Scenario 2: NASA-led mission (SGO)
  - Technology: Telescopes, laser system, interferometry, optical bench technology, GRS, charge management, torsion pendulum test benches
- China: two options, both in some degree of collaboration with ESA
  - Scenario 1: Join eLISA
  - Scenario 2: Develop a similar Chinese program
  - Technology: Telescopes, interferometry, GRS and torsion pendulum
- Japan: Decigo-Pathfinder strong candidate for a small mission by Jaxa

#### **Options:**

- L3 is one option
- US-Decadal is another
- Different collaborations
  - JAXA, National Agencies in Europe
- Let's decide in 2020 what the best way forward is!
- Get the technology ready!

#### Different views within the GW-SIG

Pessimist:

Half empty

Cornerstone in '97

SPC tolerated then?

We are not a mission yet!

Optimist:

Half full

Science Theme now!

But now: SPC approved!

ESA never cancelled a mission!

#### Realist:

Are there any other opportunities for a launch well before 2034?

Do you believe 2034?
Sitting behind L1, L2 and six M-class missions at ESA....
What if L3 is 2040 by 2020?

No, even a NASA-led mission coming out of the next Decadal would not launch earlier! No point in trying.

#### Different views within the GW-SIG

Pessimist:

Optimist:

Half empty

Half full

Corners

We are not

SPC tole

Lesson learned:

- Don't get lost in potential future opportunities presented in unrealistic launch schedules
- Get ready, stop making excuses
- We know what we need for TRL 6!
- And when the time comes (~ next Decadal), discuss how to get us to launch

Are

out of the next Decagal would not launch earlier! No point in trying.

Do you believe 2034? Sitting behind L1, L2 and six M-class missions at ESA.... What if L3 is 2040 by 2020?

low!

proved!

mission!

ming

#### Latest news:

The following technological areas are identified as of particular interest for the TPCOS Program:

- Technologies for X-ray Astrophysics, including, but not limited to, high-resolution microcalorimeter arrays, lightweight replicated optics and precision structures, highresolution gratings (both transmission and reflection).
- Technologies for Gravitational Wave Astrophysics, including, but not limited to: dimensionally stable, optical telescopes; frequency-stabilized metrology lasers; highresolution phasemeters; low-noise microthrusters; ultra-quiet inertial references; and long-distance, laser metrology techniques. [Deleted December 19, 2013]
- Technologies for CMB Polarization Measurements, including, but not limited to, high-throughput cold mm-wave telescopes and large low-background multiplexed arrays of detectors. [Deleted December 19, 2013]

SAT-Solicitation

perfect start for a successful partnership ...

#### Pathfinder:

- Launch in 2015
- Results in 2016

#### Advanced LIGO:

- Science runs start in 2015
- First detection 2016-2018

#### Technical readiness

## Scientific pressure

#### Not a mission yet. We have to be open minded:

- ESA-L3 is one option
- NASA-led is another option
- Different partners (JAXA, Nationals in Europe, ...)
- NSF, DOE?? Is this completely crazy? (Q2C)

#### Summary:

- L3 appears to be the most obvious option right now. But sorry if we are skeptical. We learned ...!
- If by 2020, L3 still has a launch date in 2034, it is probably the best way to go.
  - Maybe NASA can help to maintain schedule and enlarge mission
    - 3 arms, lifetime (orbit selection)
- If by 2020, L3 has already slipped by several years, what then?
- What if it is on the brink of cancellation (or a L3 re-competition) in Europe?
- What if ...? What if ...?

#### We have one advantage:

- SGO-mid, SGO-high, eLISA: All require the same technologies
  - 2 W laser
  - LPF-like GRS with adequate DRS (charge management etc.)
  - pm-stable telescope with low back scatter
  - µN-thrusters
  - Optical bench
  - Point ahead and breezing angle compensators
  - ...

let's develop them while we explore different mission options.

#### Summary:

- L3 appears to be the most obvious option right now. But sorry if we are skeptical. We learned ...!
- If by 2020, L3 still has a launch date in 2034, it is probably the best way to go.
  - Maybe NASA can help to maintain schedule and enlarge mission
    - 3 arms, lifetime (orbit selection)
- If by 2020
- What if it

## What if ... And if LPF is so important let's try to learn as much as we can from it!

We have one

- SGO-mi
  - 2W
  - LPF-li
  - pm-stable telescope with low back scatter
  - µN-thrusters
  - Optical bench
  - Point ahead and breezing angle compensators

let's develop them while we explore different mission options.

) in Europe?